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(54) Removing color aliasing artifacts from color digital images

(57) A method of minimizing color aliasing artifacts from a color digital image having color pixels is disclosed. The method includes providing luminance and chrominance signals from the color digital image; using the luminance and chrominance signals to compute neighborhoods of pixels which are to be processed and wherein such neighborhoods of pixels are substantially bounded by pixels defining edges; producing low frequency chrominance signals in response to the chrominance signals; using the low frequency chrominance signals and the computed neighborhood of pixels to produce noise-cleaned chrominance signals; upsampling the noise-cleaned chrominance signals to produce upsampled noise-cleaned chrominance signals; and using the luminance signals and the upsampled noise-cleaned chrominance signals to provide a color digital image having reduced color aliasing artifacts.
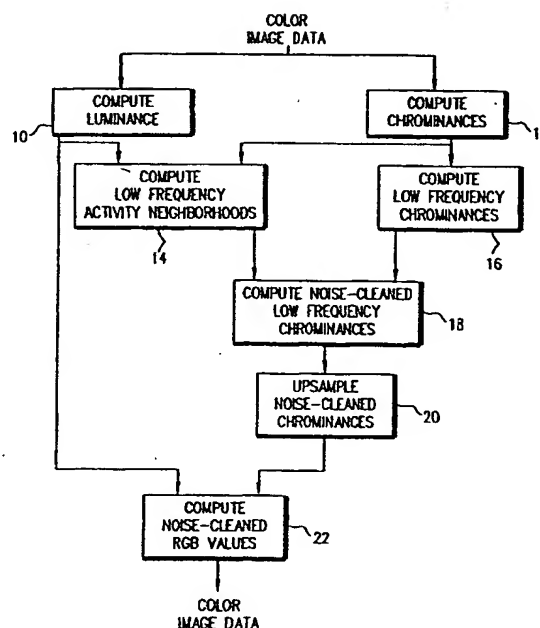
FIG. 1

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Description

[0001] The present invention relates to minimizing aliasing artifacts in colored digital images.

[0002] One type of noise found in color digital camera images appears as low frequency, highly colored patterns in regions of high spatial frequency, for example, tweed patterns in clothing. These patterns, called color moire patterns or, simply, color moire, produce large, slowly varying colored wavy patterns in an otherwise spatially busy region. Color moire patterns are also referred to as chrominance aliasing patterns, or, simply, chrominance aliasing.

[0003] There are numerous ways in the prior art for reducing color moire patterns in digital images. Among these are numerous patents that describe color moire pattern reduction methods using optical blur filters in digital cameras to avoid aliasing induced color moire in the first place. However, these blur filters also blur genuine spatial detail in the image that may not be recoverable by subsequent image processing methods.

[0004] Some approaches deal specifically with digital image processing methods for reducing or removing chrominance noise artifacts. One class of digital camera patents discloses improvements to the color filter array (CFA) interpolation operation to reduce or eliminate high frequency chrominance noise artifacts. Another class of patents teach using different pixel shapes (that is, rectangles instead of squares) and arrangements (for example, each row is offset by half a pixel width from the preceding row) with accompanying CFA interpolation operations to reduce or eliminate chrominance noise artifacts. However, these techniques address only high frequency chrominance noise, and are generally ineffective against low frequency color moire.

[0005] There is the well known technique in the open literature of taking a digital image with chrominance noise artifacts, converting the image to a luminance - chrominance space, such as CIELAB (CIE International Standard), blurring the chrominance channels and then converting the image back to the original color space. This operation is a standard technique used to combat chrominance noise. One liability with this approach is that there is no discrimination during the blurring step between chrominance noise artifacts and genuine chrominance scene detail. Consequently, sharp colored edges in the image begin to bleed color as the blurring become more aggressive. Usually, the color bleed has become unacceptable before most of the low frequency color moire is removed from the image. Also, if any subsequent image processing is performed on the image, there is the possibility of amplifying the visibility of the color bleeding. A second liability of this approach is that a small, fixed blur kernel is almost required to try to contain the problem of color bleeding. However, to address low frequency color moire, large blur kernels would be needed to achieve the desired noise cleaning.

[0006] It is an object of the present invention to provide an effective method for minimizing aliasing artifacts in color digital images.

[0007] This object is achieved in a method of minimizing color aliasing artifacts from a color digital image having color pixels comprising the steps of:

(a) providing luminance and chrominance signals from the color digital image;

(b) using the luminance and chrominance signals to compute neighborhoods of pixels which are to be processed and wherein such neighborhoods of pixels are substantially bounded by pixels defining edges;

(c) producing low frequency chrominance signals in response to the chrominance signals;

(d) using the low frequency chrominance signals and the computed neighborhood of pixels to produce noise-cleaned chrominance signals;

(e) upsampling the noise-cleaned chrominance signals to produce upsampled noise-cleaned chrominance signals; and

(f) using the luminance signals and the upsampled noise-cleaned chrominance signals to provide a color digital image having reduced color aliasing artifacts.

[0008] It is an advantage of the present invention that luminance and chrominance signals are used which not only reduce aliasing artifacts but also produce noise-cleaned chrominance signals.

[0009] Other advantages include:

Computation time is significantly reduced due to reduced number of total computations.

Highly aggressive noise cleaning with large effective neighborhoods can be performed without required large portions of the image to be resident in computer memory.

Edge detail in the image is protected and preserved during processing.

The invention is not sensitive to the initial color space representation of the image, that is, it works equally well on RGB, CMY, CMYG, or other color spaces used to define images.

FIG. 1 is block diagram which illustrates a preferred method in accordance with the present invention;

FIG. 2 is block diagram showing Block 14 in FIG. 1 in more detail;

FIG. 3 is block diagram showing Block 18 in FIG. 1 in more detail;

FIGS. 4a and 4b respectively depict two low frequency edge detection kernels used in Block 14 of FIG. 1; and

FIG. 5 depicts as shown by the arrows directions that can be taken in determining neighborhood of pixels to be processed which are produced in Block 14 and used in Block 18 of FIG. 1.

[0010]   Referring now to FIG. 1, Block 10 depicts the computation of luminance values from color digital image data which can be RGB image data. A suitable conversion would be:

$$L = (R+2 \cdot G+B)/4$$

[0011]   Block 12 depicts the computations of chrominance values from RGB image data. A suitable conversion would be:

$$C_1 = (-R+2 \cdot G-B)/4$$

$$C_2 = (-R+B)/2$$

The computation of luminance and chrominance values from a color digital image is well-known to those skilled in the art and such computation need not be described further here.

[0012]   Block 14 depicts the computation of neighborhoods of pixels which are to be processed and wherein such neighborhoods of pixels will substantially exclude pixels defining edges. This computation determines low frequency activity neighborhoods. Once such neighborhood is generated for each pixel location in the 3x downsampled image plane, and the neighborhood is used by both chrominance planes. An activity neighborhood is represented as a multiplicity of directional activity neighborhoods (a typical number is 8). Block 14 is further depicted in FIG. 2 as a sequence of four steps.

[0013]   Block 16 depicts the computation of low frequency chrominances. An effective method is to tessellate each chrominance data plane with squares having three pixels on a side. A 3x downsampling of each chrominance data plane is then accomplished by replacing the nine pixels in each square with a single pixel having, as its value, a weighted average of the nine chrominance values. A typical choice for the matrix of weights is:

```
1 2 1
2 4 2
1 2 1
```

[0014]   In FIG. 1, Block 18 depicts the production of noise-cleaned low frequency chrominance signals in accordance with the present invention. For each pixel in each of the low frequency chrominance data planes, the low frequency chrominance values within the low frequency activity neighborhood are combined to produce a noise-cleaned low frequency chrominance value. Block 18 is further depicted in FIG. 3 as a sequence of three steps.

[0015]   Block 20 depicts the upsampling of noise-cleaned chrominance values. Each noise-cleaned low frequency chrominance data plane is upsampled 3x using bilinear interpolation. These noise-cleaned chrominance data planes and the luminance data plane from Block 10 all have the same dimensions.

[0016]   Block 22 (FIG. 1) depicts the conversion of luminance and noise-cleaned chrominances into noise-cleaned RGB image data, using the inverse of the transformations performed in Block 10 and Block 12:

$$R = L-C_1-C_2$$

$$G = L+C_1$$

$$B = L-C_1+C_2$$

[0017]   Referring now to FIG. 2, where Block 14 is shown in greater detail, Block 30 depicts the computation of activity values. In this example, edge information is used to bound a computed neighborhood of pixels. For each pixel there is an activity value that depends on nearby luminance and chrominance values. For each of the three data planes, a horizontal and vertical activity value is computed by taking weighted sums of data. The horizontal and vertical weight kernels are shown in FIGS. 4a and 4b, respectively. The absolute values of the resulting six values are added together and the result is the activity value of the current pixel. It will be appreciated by those skilled in the art, that FIGS. 4a and 4b are low frequency edge detection kernels that are used in Block 30 for computing activity values.

[0018]   In FIG. 2, Block 32 depicts the computation of low frequency activity vectors. The process begins by tessellating the activity value data plane with squares having three pixels on a side. For each 3x3 square, an activity vector is created having three components. The first component is the activity value found in the center of the 3x3 square. The second component is the second smallest of the nine activity values found in the 3x3 square. The third component is the second largest of the nine activity values found in the 3x3 square. The three components of the low frequency activity vectors can be considered to be trend numbers. These trend numbers are used in Block 34 to determine the neighborhood of pixels. In this example a desired characteristic of the neighborhood of pixels is that they are bounded by edges. As will be explained, other image characteristics can also be used in accordance with the present invention to bound a neighborhood of pixels. More particularly, the trend numbers are used to define the maximum number of pixels in a plurality of directions from the pixel of interest. This results in determination of the neighborhood of pixels which includes the maximum number of pixels identified. This is shown in FIG. 5.

[0019]   Block 34 depicts the computation of directional low frequency activity neighborhoods. The depicted preferred embodiment utilizes 8 directions as depicted in FIG. 5, although it is understood that a different number

of directions might be used instead. For any selected pixel, let A_0 denote the first component of its activity vector. From the selected pixel, 8 directional low frequency activity neighborhoods are generated as follows. Beginning at the selected pixel and proceeding in a particular direction, inspect the next pixel and let A_{lo} and A_{hi} denote the second and third components of its activity vector, respectively. If both absolute values, $ABS(A_0 - A_{lo})$ and $ABS(A_0 - A_{hi})$, are less than or equal to a preset threshold T (for example 60 for a 12-bit image), then this pixel is accepted as a member of the directional low frequency activity neighborhood and the process continues with the next pixel in the same direction.

[0020] If either absolute value exceeds T, the pixel is rejected and the process for that particular direction stops. The process is also stopped when the neighborhood reaches a preset maximum number of members (for example 10 pixels). Because directional low frequency activity neighborhoods do not include the original selected pixel, it is possible for them to be empty.

[0021] Finally, Block 36 of FIG. 2 depicts the computation of low frequency activity neighborhoods. The selected pixel together with all of the directional low frequency activity neighborhoods comprise the low frequency activity neighborhood of the selected pixel.

[0022] Block 14 is particularly suitable for use in ensuring that the neighborhood of pixels do not include edges. Neighborhood of pixels can not only be based upon excluding edges but also can be used so as only to include key colors such as flesh, sky, foliage and grass. Moreover, the neighborhood of pixels can be used to include only texture and untextured regions such as clothing, hair and masonry work or highlights and shadows. Still further, other special objects of interest such as human faces, automotive vehicles and text can be used.

[0023] Referring now to FIG. 3, Block 40 depicts the computation of weighted chrominance values for the directional low frequency activity neighborhoods. For each direction, consider the pixels in the corresponding activity neighborhood. Each pixel has a low frequency chrominance value which is multiplied by a weight which is determined by the pixel's position in the neighborhood. If Cjk is the kth chrominance value in the jth directional activity neighborhood, and if Wk is the weight corresponding to the kth position, then Cj is the weighted average chrominance value for the jth directional activity neighborhood, and its value is computed according to:

$$ Cj = \left(\sum_k CjkWk \right) \bigg/ \left(\sum_k Wk \right) $$

[0024] A representative choice for the weights is:

1,1, ... ,1,0

This set of weights shows all points in the directional activity neighborhood getting a weigh of one except the most distant pixel which gets a weight of zero. It is understood that other weight assignments are possible.

[0025] Block 42 in FIG. 3 depicts the filtration of weighted chrominance values. For each chrominance data plane, the weighted chrominance values from Block 42 are sorted by size. The highest and lowest values are discarded and the remaining chrominance values, together with the sums of their weights, are passed to Block 44. If there are fewer than three non-empty directional neighborhoods, the filtration process will pass no filtered chrominance values at all. The filtration process is done separately for each chrominance data plane.

[0026] Finally, Block 44 of FIG. 3 depicts the combination of pixel chrominances with the filtered chrominance values from Block 42. The filtered chrominance values are weighted by their individual sum of weights and combined with the selected pixel's chrominance value with a weight of unity. The result is a noise-cleaned low frequency chrominance value for the selected pixel. This process is done separately for both chrominance data planes. If there no filtered chrominance values are passed in from Block 42, then no change is made to the chrominance values at the selected pixel.

[0027] It will be understood by one skilled in the art that the present invention can be used as part of a digital image processing chain and that it can be put in sequence with other image processing steps.

Claims

1. A method of minimizing color aliasing artifacts from a color digital image having color pixels comprising the steps of:

    (a) providing luminance and chrominance signals from the color digital image;
    (b) using the luminance and chrominance signals to compute neighborhoods of pixels which are to be processed and wherein such neighborhoods of pixels substantially are bounded by pixels defining edges;
    (c) producing low frequency chrominance signals in response to the chrominance signals;
    (d) using the low frequency chrominance signals and the computed neighborhood of pixels to produce noise-cleaned chrominance signals;
    (e) upsampling the noise-cleaned chrominance signals to produce upsampled noise-cleaned chrominance signals; and
    (f) using the luminance signals and the upsam-

pled noise-cleaned chrominance signals to provide a color digital image having reduced color aliasing artifacts.

2. The method of claim 1 wherein step (a) is accomplished a plurality of times to produce the reduced resolution color digital image.

3. The method of claim 1 wherein the color pixels in a neighborhood of pixels are selected so that color pixels to be averaged do not extend over and beyond an adjacent edge.

4. In a method for image processing, a color digital image and which includes minimizing color aliasing artifacts from a processed color digital image comprising the steps of:

> (a) image processing a input color digital image to produce a new color digital image having a modified representation than the input color digital image;
> (b) reducing the number of color pixels in the input color digital image or the new color digital image to provide at least one lower resolution color digital image;
> (c) converting the lower resolution color digital image into a space having luminance and chrominance content;
> (d) reducing aliasing artifacts in the chrominance content of the lower resolution color digital image by averaging chrominance values in a neighborhood of a color pixel of interest, wherein the color pixels averaged adjacent the color pixel of interest is related to the distance from an adjacent edge in the color digital image;
> (e) interpolating the aliasing reduced chrominance content to a higher resolution; and
> (f) using the original luminance content and the interpolated chrominance content to provide a color digital image which is either the input color digital image or the new color digital image so that the processed digital image has minimized color aliasing artifacts.

5. A method of computing neighborhoods of pixels which neighborhoods are bounded to include particular image characteristics comprising the steps of:

> (a) using the digital image to compute neighborhoods of pixels which are to be processed and wherein such neighborhoods of pixels are substantially bounded by pixels defining the particular image characteristic;
> (b) computing an activity number for each pixel based upon the values of adjacent pixels;
> (c) using the activity numbers for each pixel and

activity numbers for adjacent pixels in a predetermined neighborhood to produce a plurality of trend numbers for each pixel related to the particular image characteristic; and
(d) using the trend numbers for each pixel to determine the neighborhoods of pixels which bound the particular image characteristic.

6. The method of claim 5 wherein the particular image characteristics are edges, flesh tones, highlights and shadows, specific colors, texture and specific objects of interest.

7. The method of claim 5 wherein in step (d) the trend numbers are used to define the number of pixels in a plurality of directions from the pixel of interest.

8. The method of claim 5 wherein the predetermined neighborhood of pixels is determined by using kernels which include weighted average numbers.
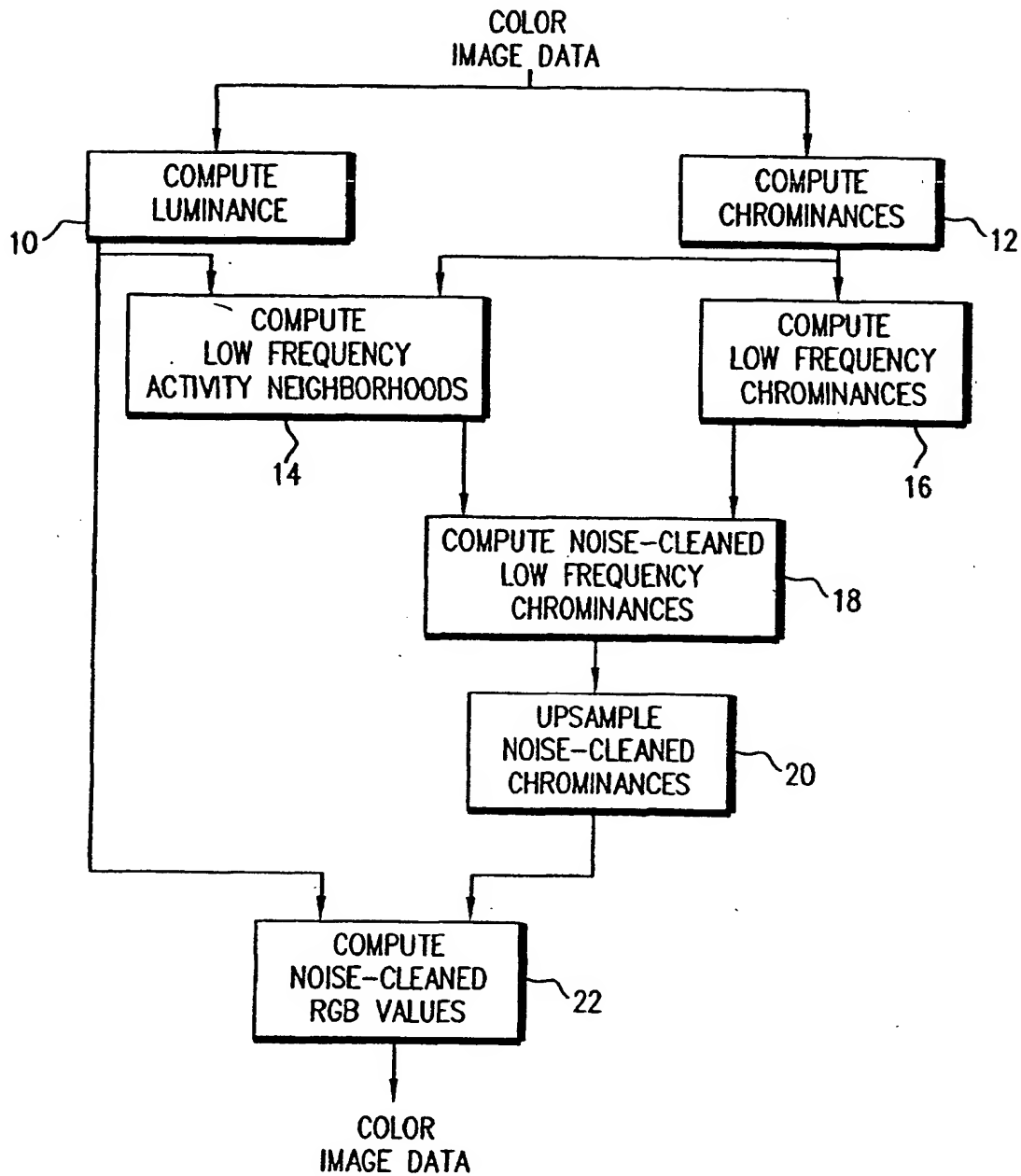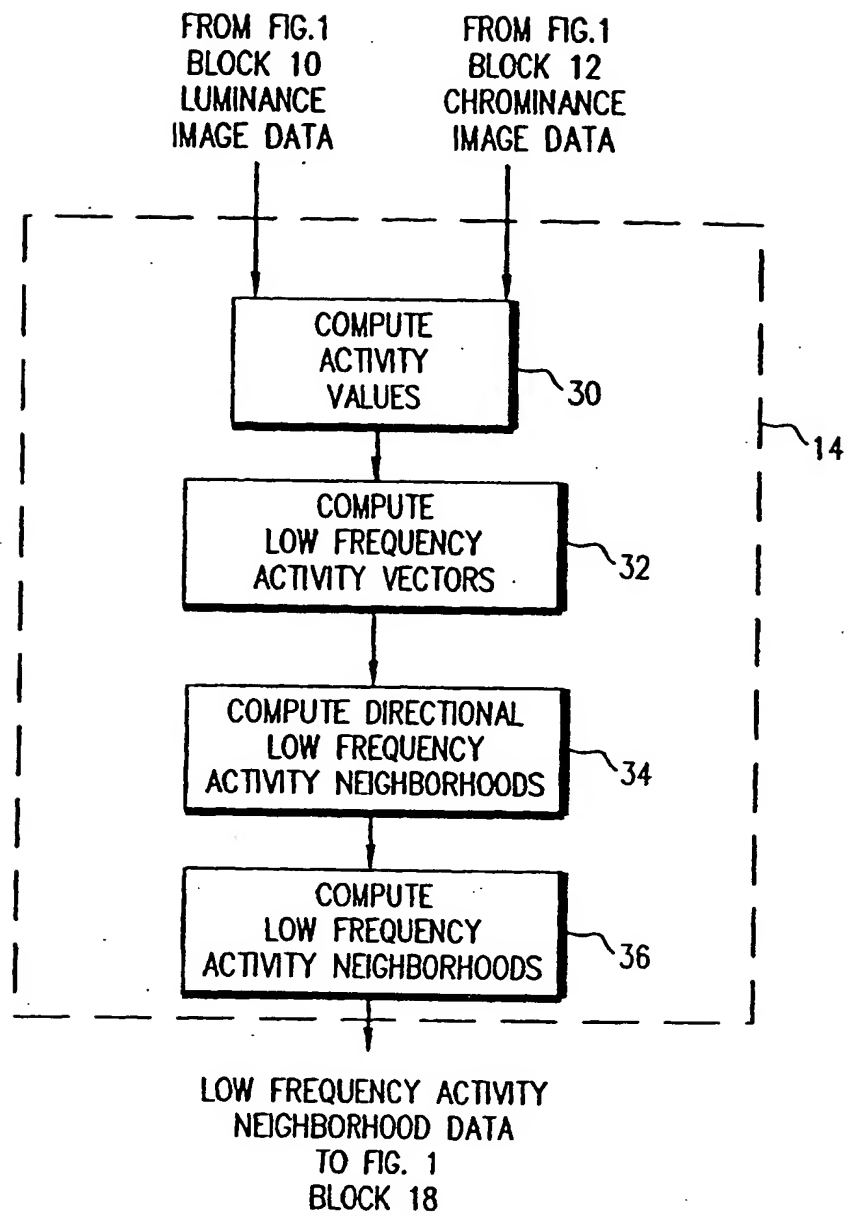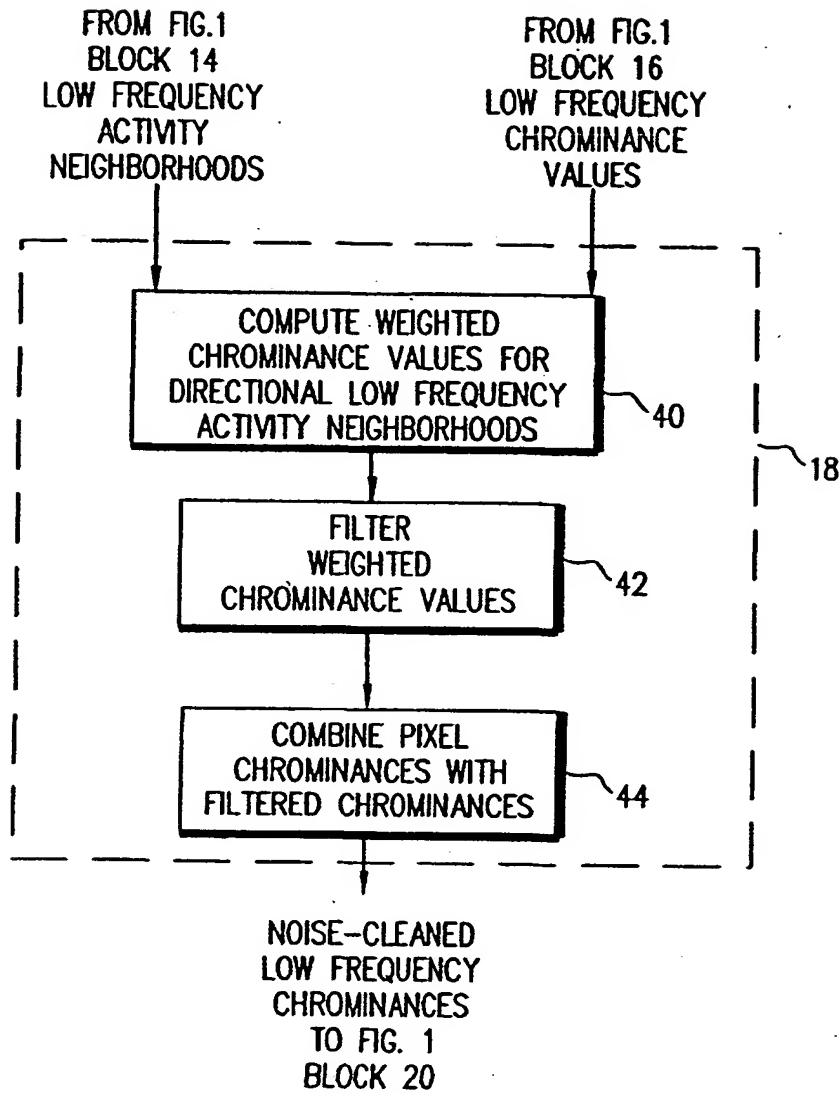
COLOR
IMAGE DATA

```
COMPUTE                          COMPUTE
LUMINANCE                        CHROMINANCES
   10                                         12
```

```
        COMPUTE                      COMPUTE
     LOW FREQUENCY                 LOW FREQUENCY
  ACTIVITY NEIGHBORHOODS            CHROMINANCES
        14                                   16
```

```
     COMPUTE NOISE-CLEANED
        LOW FREQUENCY
         CHROMINANCES              18
```

```
         UPSAMPLE
        NOISE-CLEANED
        CHROMINANCES         20
```

```
         COMPUTE
       NOISE-CLEANED
       RGB VALUES        22
```

COLOR
IMAGE DATA

FIG. 1

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FROM FIG.1
BLOCK 10
LUMINANCE
IMAGE DATA

FROM FIG.1
BLOCK 12
CHROMINANCE
IMAGE DATA

COMPUTE
ACTIVITY
VALUES
30

14

COMPUTE
LOW FREQUENCY
ACTIVITY VECTORS
32

COMPUTE DIRECTIONAL
LOW FREQUENCY
ACTIVITY NEIGHBORHOODS
34

COMPUTE
LOW FREQUENCY
ACTIVITY NEIGHBORHOODS
36

LOW FREQUENCY ACTIVITY
NEIGHBORHOOD DATA
TO FIG. 1
BLOCK 18

FIG. 2

FROM FIG.1
BLOCK 14
LOW FREQUENCY
ACTIVITY
NEIGHBORHOODS

FROM FIG.1
BLOCK 16
LOW FREQUENCY
CHROMINANCE
VALUES

COMPUTE WEIGHTED
CHROMINANCE VALUES FOR
DIRECTIONAL LOW FREQUENCY
ACTIVITY NEIGHBORHOODS
40

18

FILTER
WEIGHTED
CHROMINANCE VALUES
42

COMBINE PIXEL
CHROMINANCES WITH
FILTERED CHROMINANCES
44

NOISE—CLEANED
LOW FREQUENCY
CHROMINANCES
TO FIG. 1
BLOCK 20

FIG. 3

-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	-2	-2	-2	-2	-2	-2	-2	-1
-1	-2	-3	-3	-3	-3	-3	-2	-1
-1	-2	-3	-4	-4	-4	-3	-2	-1
0	0	0	0	0	0	0	0	0
1	2	3	4	4	4	3	2	1
1	2	3	3	3	3	3	2	1
1	2	2	2	2	2	2	2	1
1	1	1	1	1	1	1	1	1

FIG. 4a

-1	-1	-1	-1	0	1	1	1	1
-1	-2	-2	-2	0	2	2	2	1
-1	-2	-3	-3	0	3	3	2	1
-1	-2	-3	-4	0	4	3	2	1
-1	-2	-3	-4	0	4	3	2	1
-1	-2	-3	-4	0	4	3	2	1
-1	-2	-3	-3	0	3	3	2	1
-1	-2	-2	-2	0	2	2	2	1
-1	-1	-1	-1	0	1	1	1	1

FIG. 4b

FIG. 5

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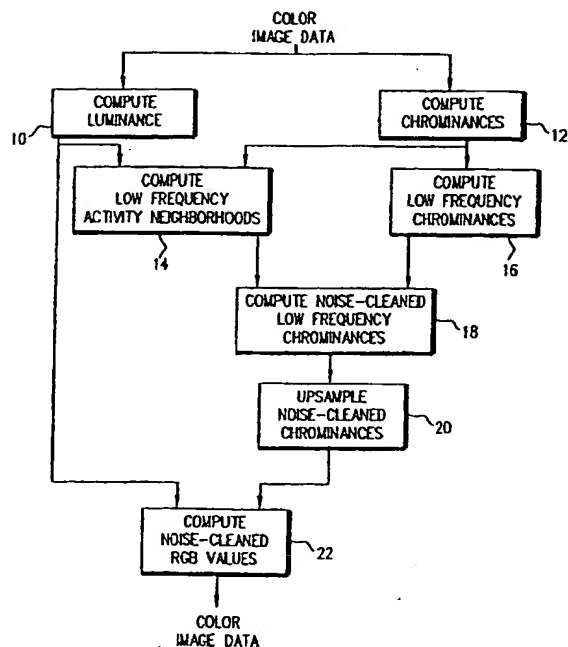
FIG. 1

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European Patent Office

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	17 August 2004	Casteller, M

ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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